IEEE 802 Tutorial

Energy Efficiency and Regulation

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Agenda

Energy Context

- Energy and Networks
- Existing Policies
- Testing

802 Topics

- Energy Efficient Ethernet
- Link Layer Discovery Protocol
- Audio Video Bridging / EEE
- Audio Video Bridging / Idle
- WiFi
- WiMAX

Open Discussion

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Why care about electronics, energy?

- Core
  - Carbon
  - Energy
  - $$€€£¥
- Extreme conditions
  - Power deserts (no mains)
  - Power oceans (datacenters)
  - Power ponds (e.g. notebook)
- Most energy policy for “power reservoirs”
  - Man-made, controlled, increasingly burdensome

Networks and Energy

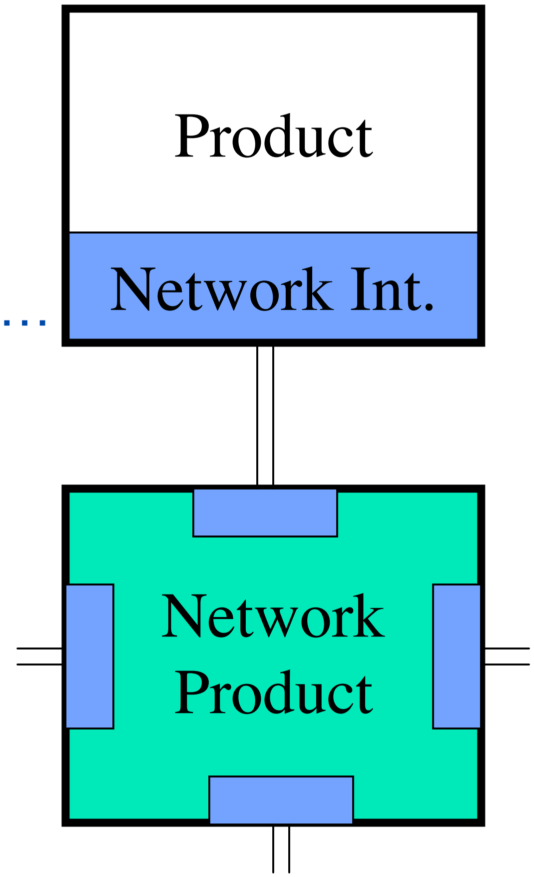
Network equipment ….

Routers, switches, modems, wireless APs, …

… vs **networked** equipment

<u>Electronics</u>: PCs, printers, set-top boxes, …

<u>Non-electronics</u>: lighting, heating, appliances, …



<u>How networks drive energy use</u>

- **Direct**
  - Network interfaces (NICs)
  - Network products
- **Induced** in Network<u>ed</u> products
  - Increased power levels
  - Increased time in higher power modes (to maintain network presence)

Network induced consumption **>** **all** direct

Electronics energy use (U.S. only)

- Over 10% of buildings electricity (residential & commercial)
  - Buildings about 70% of all electricity
  - Electronics nearly 300 TWh/year or about $30 billion/year
- Almost 60% in residential buildings
  - Well under 20% in data centers
- An increasing portion are digitally networked

"Non-Electronics"

- Everything else: Lighting, Heating/Cooling, Appliances, etc.
- Will be increasingly networked
  - Need low-energy technologies
  - Energy invested in network connection - hope to save more
- Test procedures and standards need to account for this

Challenges networks bring to public policy

- Maximize efficiency of network equipment
  - In typical use
- Fairly measure, evaluate products with network interfaces
- Define goals for new technologies or standards
  - Functional
  - Energy/power
- Need and desire for persistent availability

Public policy and energy efficiency

- Basic goal: Obtain energy savings that also save money
  - Response to rampant market failures
  - To meet energy security and environmental goals
- Many tools
  - Orientation: consumer, retailer, manufacturer, standards, utility, public purchasing, …
  - Rebates and other economic incentives
  - Energy standards: buildings, appliances, lighting, …
  - Mandatory and voluntary
  - Modal (power) vs. Annual (energy) vs. Non-energy
  - Horizontal vs. Vertical
- Challenge: Find right mix of tools for each circumstance

Existing policies

European Union - Codes of Conduct

- Broadband Equipment and Set-top boxes
  - Customer and service provider
  - Base levels for many product types
    - Per-port for service provider equipment
  - Power levels by mode
  - Levels drop over time
  - Power adders for additional interfaces
  - Test procedure not defined
- Data Centers
  - Not specific about networks

http://re.jrc.ec.europa.eu/energyefficiency/

Existing policies

EU “Energy Using Products” (EUP)

- “Lot 6” - Standby Losses
  - Products - includes CE and IT for “domestic environment”
  - Did not cover modes with network connectivity

    “When the EuP is in **Lot 6 standby** according to (iii.) and offers either a **remote network reactivation** and / or **network integrity communication**, then the product is considered to be in **Networked Standby** mode.” (emphases added)
  - Levels
    - 2011 - 1 W (2 W with display)
    - 2014 - 0.5 W (1 W with display)

ecostandby.org *(“documents” page)*

Existing policies

EU "Energy Using Products" (EUP)

"Lot 26" - Networked Standby Losses

- Research initiated June, 2009
- Final report due December, 2009
- Expect will attempt to coordinate / harmonize with rest of world
- In scope: Residential and commercial, IT and CE, phones, "building sensors and control"
- Interest in both 802 layers and higher
- *Opportunity*: Collectively develop principles to embody in Lot 26 and elsewhere

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Existing policies

Energy Star

- General: Expect to add requirement for EEE when feasible
- PCs
  - Test with network connection active at highest speed capable of
  - Requirements for presence of Wake-On-LAN
  - Reward for systems that implement “Proxying”
    - see: efficientnetworks.lbl.gov/enet-proxying.html
- Imaging Equipment (printers, copiers, etc.)
  - Test with 1-3 data/network connections active
  - Sleep power level “adders” for interfaces

Existing policies

Energy Star, cont.

Imaging Equipment Sleep power "adders" *(W)*

- "Primary" = active; "Secondary" = unconnected

	Primary	Secondary
Wired < 20 MHz USB 1.x, IEEE488, IEEE 1284/Parallel/ Centronics, RS232, and/or fax modem	0.3	0.2
Wired ≥ 20 MHz and < 500 MHz USB 2.x, IEEE 1394/FireWire/i.LINK, and 100Mb Ethernet	0.5	0.2
Wired ≥ 500 MHz 1 G Ethernet	1.5	0.5
Wireless Bluetooth and 802.11	3.0	0.7
Wired card/camera/storage	0.5	0.1
Infrared	0.2	0.2

Existing policies

Energy Star, cont.

- Network equipment
  - Preliminary study - no formal announcement yet
  - Consumption and potential savings seem to warrant labeling program
  - Separate processes for small and large devices
    - Small: soon - Large: next year
  - First focus - products with largest total consumption and where label appropriate
  - For announcements: kaplan.katharine@epa.gov

Existing policies

Horizontal standards

- Test procedures or requirements applied to many different product types
- Common elements of “vertical” test procedures, requirements

Examples

- IEA “1-watt” initiative
- DOE/FEMP standby requirements for federal purchasing
- EISA - Energy Independence and Security Act (2007)
- EU EUP “Standby and Off” requirements
- Energy Star external power supply specification
- IEC 62301 low power mode measurement procedure

The “Smart Grid” and 802

- An important topic, but **<u>not</u>** for this tutorial
  - “Using network to reduce non-electronic energy use”
- Our topics
  - Energy use of network interfaces
  - Energy use of network equipment
  - Energy use of other electronic products

Other Physical Layers?

- Consider “Internet 0” — cba.mit.edu/projects/I0/

  ng.cba.mit.edu/show/09.04.i0_PHY.html

METI and ATIS

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METI

METI Top Runner - overview

省エネのシンボルです
SMART CLOVER

- Top Runner is…
  - Japan’s approach to energy usage reduction
  - First introduced in 1999 (development from 1979)
  - More than 20 products (from trains to rice cookers)
  - Voluntary compliance – advantages for “top runners”
- How Top Runner works…
  - Targets set based on extensive product testing
  - (generally) New products should match current top 20%
  - Targets updated regularly
  - Rewards technology leaders

<u>More info.</u>

Please refer to the following URL for more information about METI Top Runner Program

The Energy Conservation Center, Japan : http://www.eccj.or.jp/index_e.html

Top Runner Program brochure (English) : http://www.eccj.or.jp/top_runner/img/32.pdf

Top Runner for networking

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SMART CLOVER

- Small routers, L2 switches – introduced 2008
  - Routers (max 200Mb/s, no VPN), wired/wireless/DSL
  - L2 switch, managed/unmanaged – 100M, 1G, 10G
  - Each set divided to subcategories
  - Target power per system (or per port for L2 switching)
  - Also covers PoE
- Other routers, L3 switches – target 2010
  - Testing in progress, analysis of results
  - Categorization still being decided
  - Test traffic based on minimal functions
  - Other features disabled

Energy saving label

ATIS – TEER approach

- Full system testing – no targets
  - Covers most large (wired) network devices
  - Philosophically – measure max throughput & typical power
  - Categories define test environment
  - Test is intended to replicate realistic usage
- General comments
  - Measuring typical power reflects real-world energy costs
  - Recognizes the useful function of networks
    - Availability of capacity is key
  - Rewards scalable design:
    - High max throughput, low power at low utilization
  - Fits well with 802.3az philosophy

Other approaches to metrics

- Power per function approach
  - (e.g. EuP Broadband Code of Conduct)
  - Simplistic – one power target for a function
    - Does not differentiate quality of function
    - Does not reward scalability
- Max throughput / max power approach
  - Encourages “magazine test” optimized architecture
  - Does not reflect real world energy usage
  - Similar problems with idle power only approach
- Specific feature (check box) approach
  - Recognizes holistic effect of some features
  - Useful alongside other metrics (e.g. used in Energy Star)

Testing and Evaluation

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Evaluation Structure

- Test conditions
- Test procedures
- Metrics
- Specifications
  - Structures
  - Values

Test Procedure Issues

- Want to estimate typical energy use
  - Number of features × Number of configurations
  - Most equipment provisioned for peak load
  - Peak power vs. Idle power vs. Typical power
- Must test a subset of features & configurations
  - Need to account for features present & operating
- Preferred approach
  - Test max throughput & typical power
- Other approach
  - Test max throughput and power only
  - Test low throughput and power only

Metrics & Specifications

- Define metrics
  - Capacity (throughput, number of ports)
  - Power (typical, maximum, idle, etc)
- Specifications that are not specific
  - Provide meaningful differentiation
  - Reduce energy while maintaining performance
  - Provide choice to the consumer (features, manufacturers)
  - Do not rely on proprietary technology

Test Conditions for 802

- General
  - Traffic patterns (ATIS vs METI approach)
  - Multi rate selection
  - Capabilities of connected devices
- Wired technologies
  - Cable length (Automatic power selection)
- Wireless
  - Radio environment issues

Energy Context Summary

- Align public policy with current and future technology
- Align roadmaps with energy policy goals
- As much horizontal uniformity as possible
  - Test conditions & procedures
  - Requirements structures & values
  - Across product types, countries, time

Energy Efficient Ethernet

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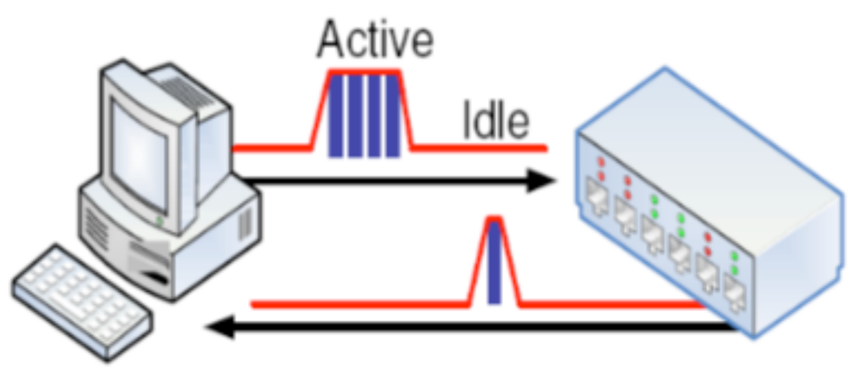
What is Energy Efficient Ethernet (EEE)

- Also known as IEEE 802.3az
- EEE is a method to facilitate transition to and from lower power consumption in response to changes in network demand
  - In the process of being specified for these copper PHYs
    - 100BASE-TX (Full Duplex)
    - 1000BASE-T (Full Duplex)
    - 10GBASE-T
    - 10GBASE-KR
    - 10GBASE-KX4
    - 1000BASE-KX
  - Uses Low Power Idle (LPI) to save energy

What is Low Power Idle?

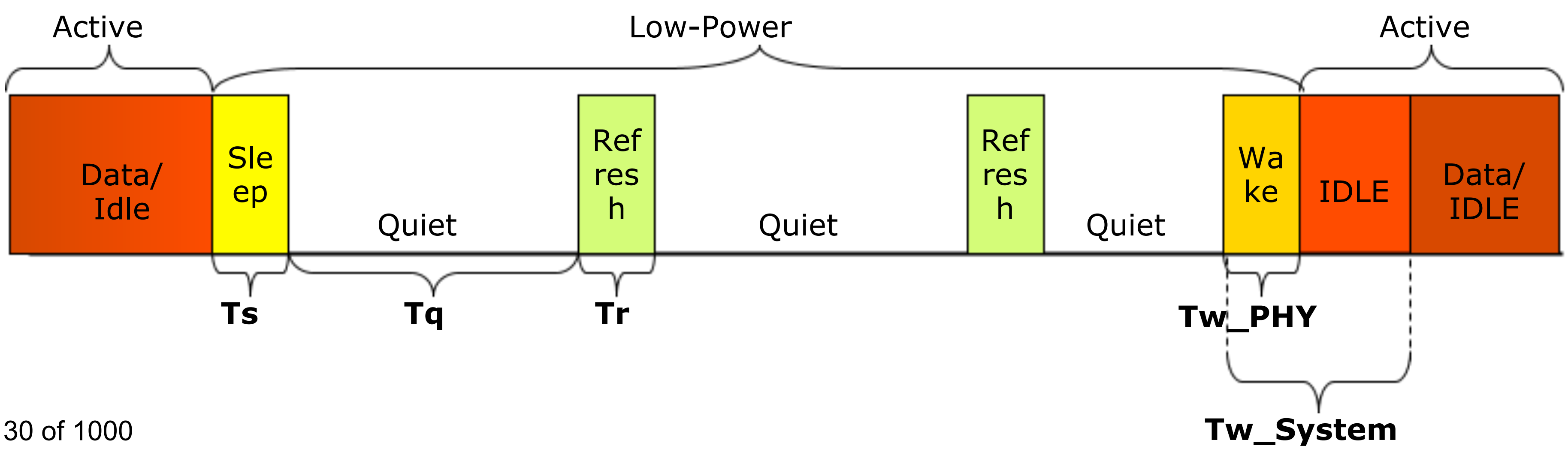
- Concept: Transmit data as fast as possible, return to Low-Power Idle
- Saves energy by cycling between Active and Low Power Idle
  - Power reduced by turning off unused circuits during LPI
  - Energy use scales with bandwidth utilization



What is Low Power Idle?

- A closer look
  - PHY Wake Time values are in the order of 10's of microseconds

Term	Description
Sleep Time (Ts)	**Duration PHY sends Sleep symbols before going Quiet.**
Quiet Duration (Tq)	**Duration PHY remains Quiet before it must wake for Refresh period.**
Refresh Duration (Tr)	**Duration PHY sends Refresh symbols for timing recovery and coefficient synchronization.**
PHY Wake Time (Tw_PHY)	**Duration PHY takes to resume to Active state after decision to Wake.**
System Wake Time (Tw_System)	**Wait period where no data is transmitted to give the receiving system time to wake up.**

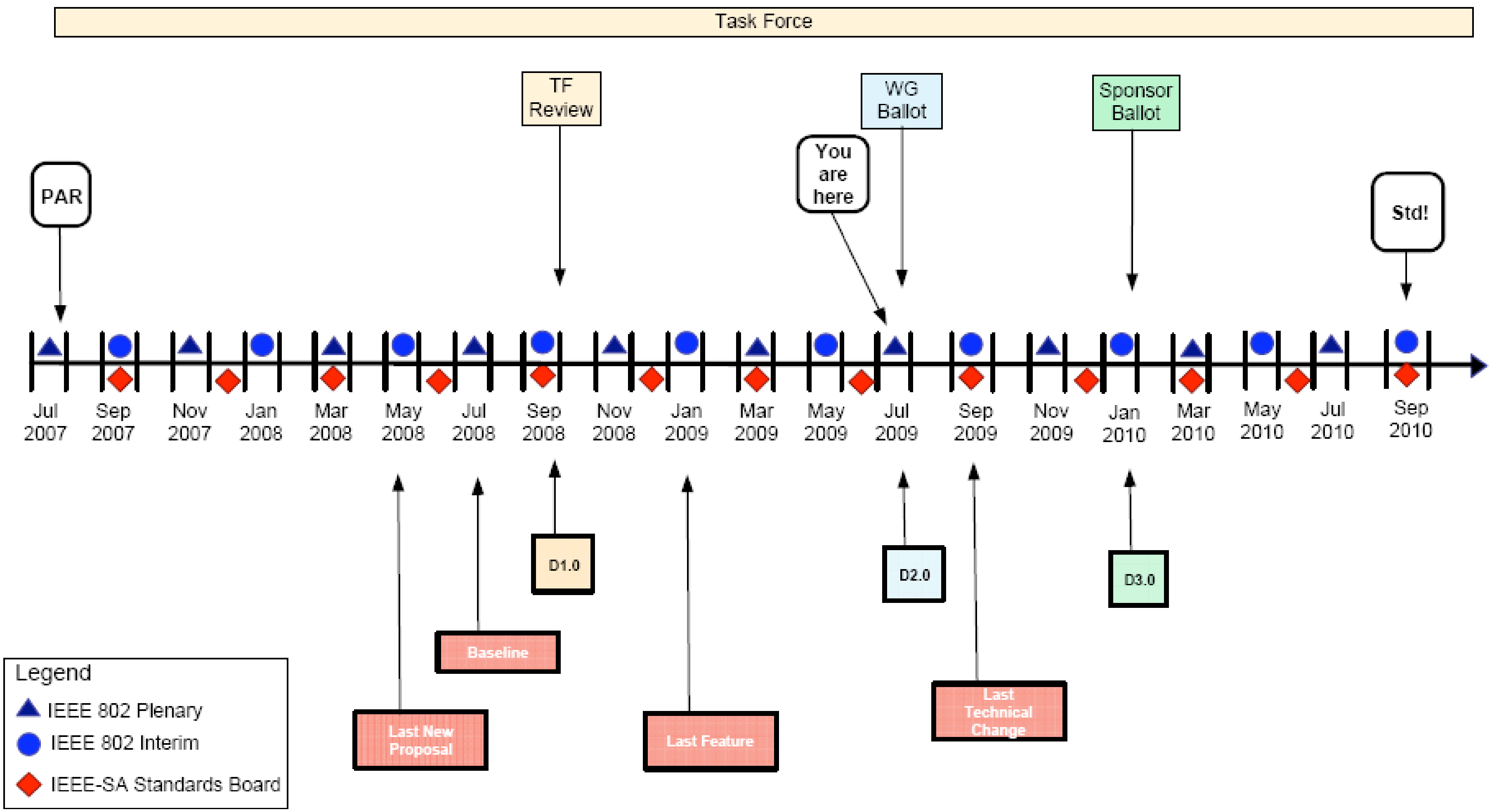


Optimizing Energy Efficiency

- Energy Efficiency can be optimized by using link-partner communications after the link is established
  - Use Link Layer Discovery Protocol (LLDP) to change wake times.
  - The longer the wake time, the longer the delay till frames can pass, i.e. latency increases
  - Trade-off between energy savings and latency
- There are system power savings opportunities in addition to PHY power savings

State of the standard

- Hoping to go to 802.3 Working Group Ballot at the end of the week
- If we stay on track, should be finished Sept. 2010



Final thoughts …

- The 802.3az Task Force estimated 75% of PHY power savings possible using Low Power Idle
  - Assuming 100% adoption in the US alone that translates to roughly \$300M to \$470M per year in savings
    - Does not include cooling or additional system power savings
- Test specifications are currently being developed
  - This should ease the task of specifying qualifications for Energy Star, etc.
- More work to do?
  - Energy Efficient Ethernet is not specified for optical PHYs and some copper PHYs
    - For example, 802.3ba
  - Should there be a higher layer power management specification?

Using LLDP for Saving Energy in 802.3

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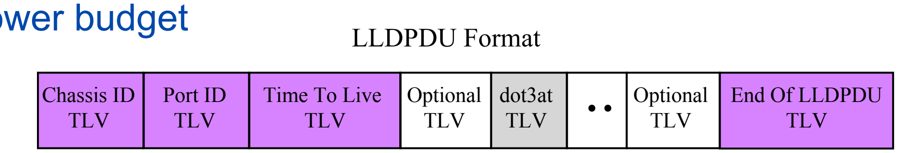
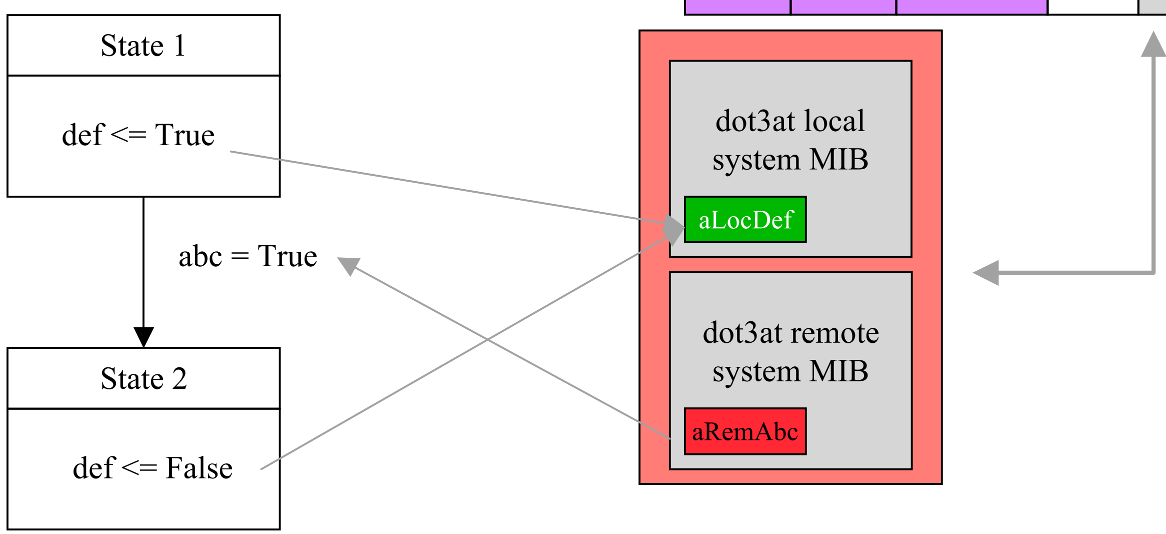
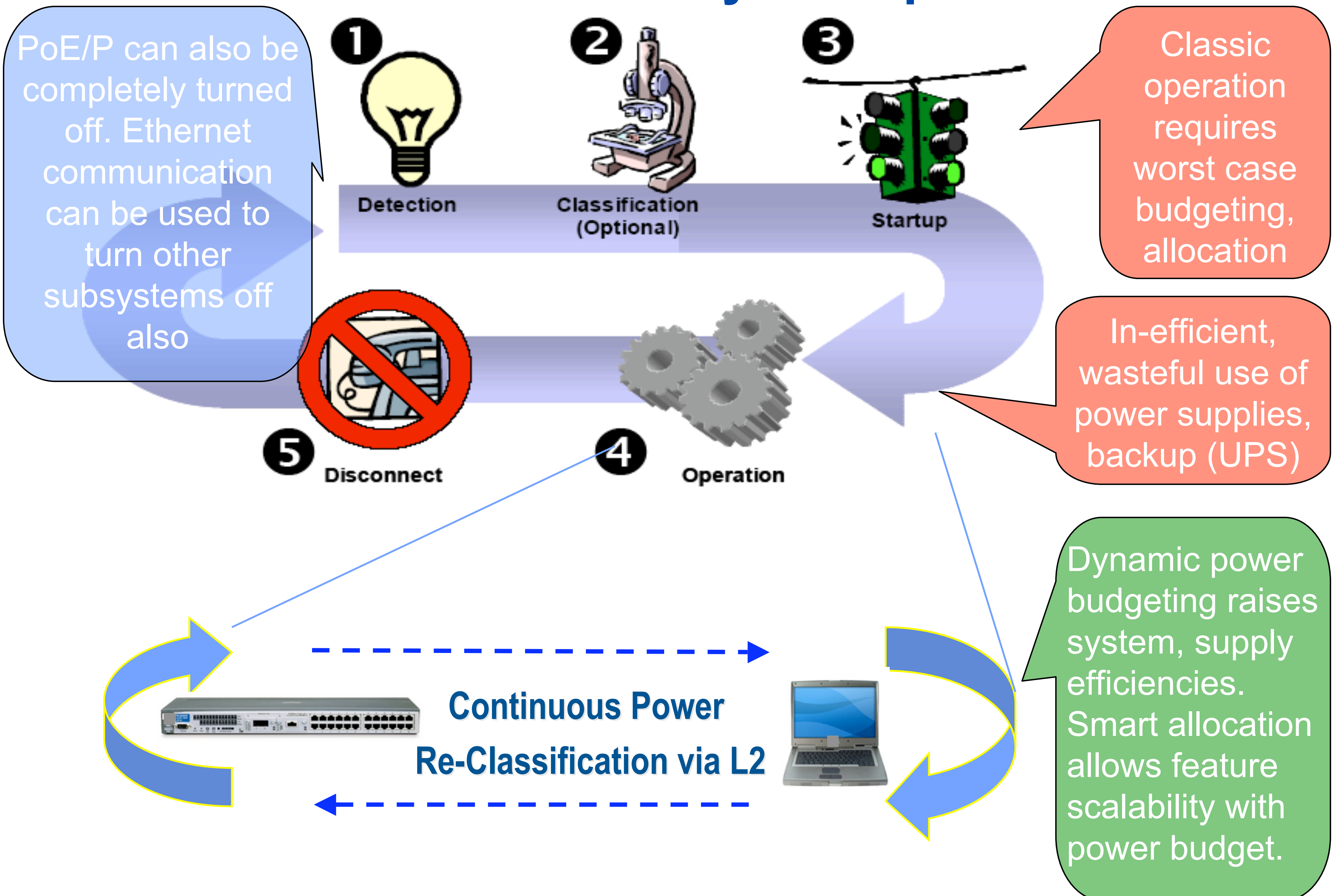
802.3at’s and 802.3az’s Layer 2

- **Officially called “Data Link Layer”**
- **Communications based energy policy enables enhanced savings**
- **Several Components: (a) Transport (b) State machine (c) MIB (d) Features**
- **In EEE allows for the dynamic negotiation of wake up time for RX**
  - Allows for cascaded interfaces
  - Deeper sleep modes
  - Fallback
  - Efficient buffering
- **In PoEP allows for the dynamic negotiation of power allocation for PD**
  - Power budgeted when it is needed, supplies operate at near optimal efficiency point, power backup systems and batteries optimized for load (e.g. UPS)
  - Smart allocation: Features scalability with power budget
- **Nearly identical SMs for PoEP and EEE**

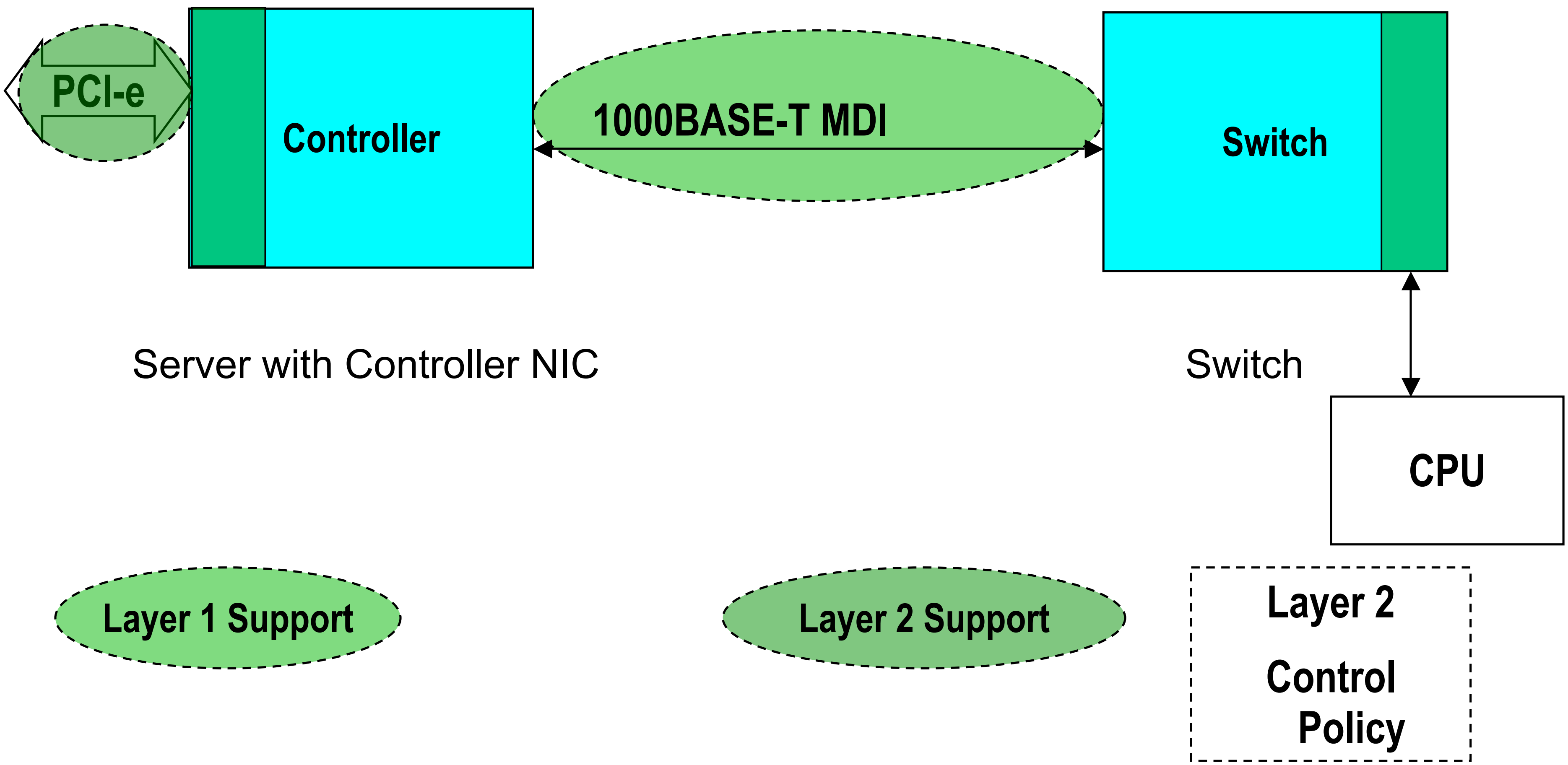




PoE/P Enhanced Layer 2 Operation



EEE Enhanced Layer 2 Operations



- **Opportunity to save additional power within a box (link partner)**
  - Additional circuits beyond the PHY can be turned off
- **Additional RX wakeup time negotiated using 802.3az's Layer 2 --- *standards based***

Audio/Video Bridges
and
Energy Efficient Ethernet

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Why Worry about AVB & EEE?

- In the future, many consumer devices will be connected with AVB over 802 networks, both wired and wireless
- If AVB use precludes the energy saving modes of the network then the result is more energy costs to the consumer, especially in a lightly loaded home environment
- This presentation will focus on AVB and EEE, but other work is proceeding to address AVB and 802.11 power saving modes

Why does AVB care about EEE?

- AVB transports stream frames from a talker to a listener with a guaranteed maximum delivery latency
- Time to access the media could mean that additional latency is added to the worst case
- But AVB knows something about its traffic that can help know when energy savings are possible

What will AVB do about EEE?

- Make sure transmission selection works so that EEE media access latency and other components of worst case latency are mutually exclusive
- Allow EEE media access latency to grow only when streams are not active on a link
- Define when EEE goes to low power — such as, between stream frames

What should you do?

For all networking standards

- Look for power savings in your standard
- Make sure your standard isn't in the way of power savings by another standard it relies on
- Help your standard's clients save power

Enabling Power Savings In An AVB Cloud

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Enabling Power Savings In An AVB Cloud

- 802.1as protocol includes periodic messages sent between time-aware nodes (bridge or stations)
- 802.1as did not expect clock discontinuities in the receiver
  - this would have force the receiver to keep its clock running in any state

- Power management support was addressed late in the development but early enough to allow the protocol to be modified

- A new signaling message was added to
  - allow the message receiver to specify the periodicity of the messages it wish to receive from the sender
  - to permit the receiver to indicate whether the timing information provided in the response message is valid or not

802.11 Wireless LAN (WiFi)

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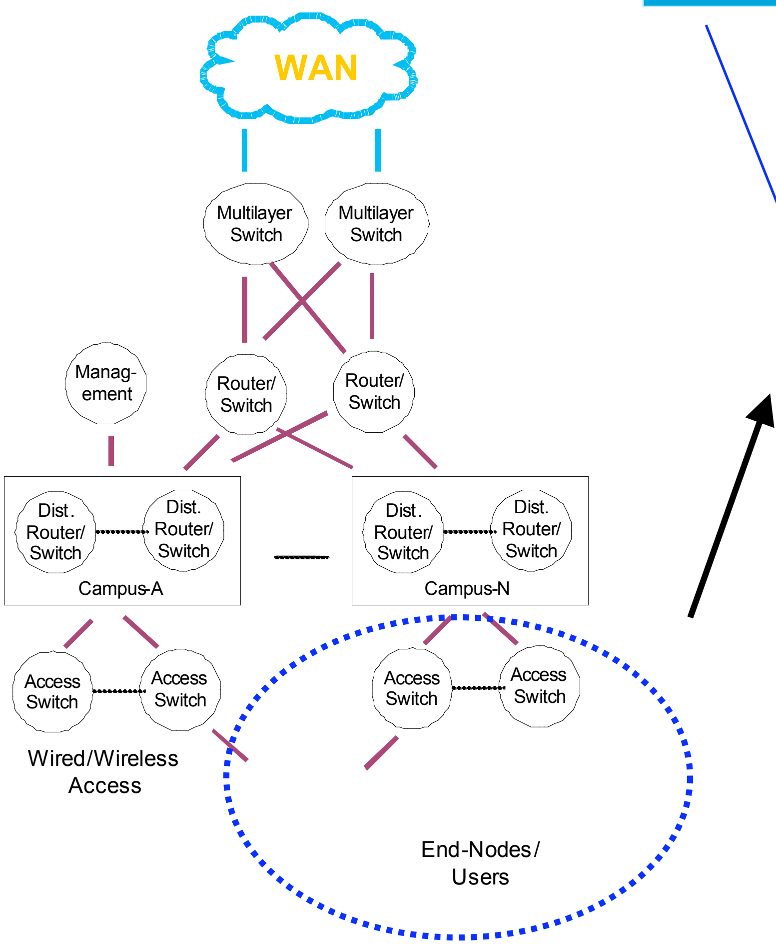
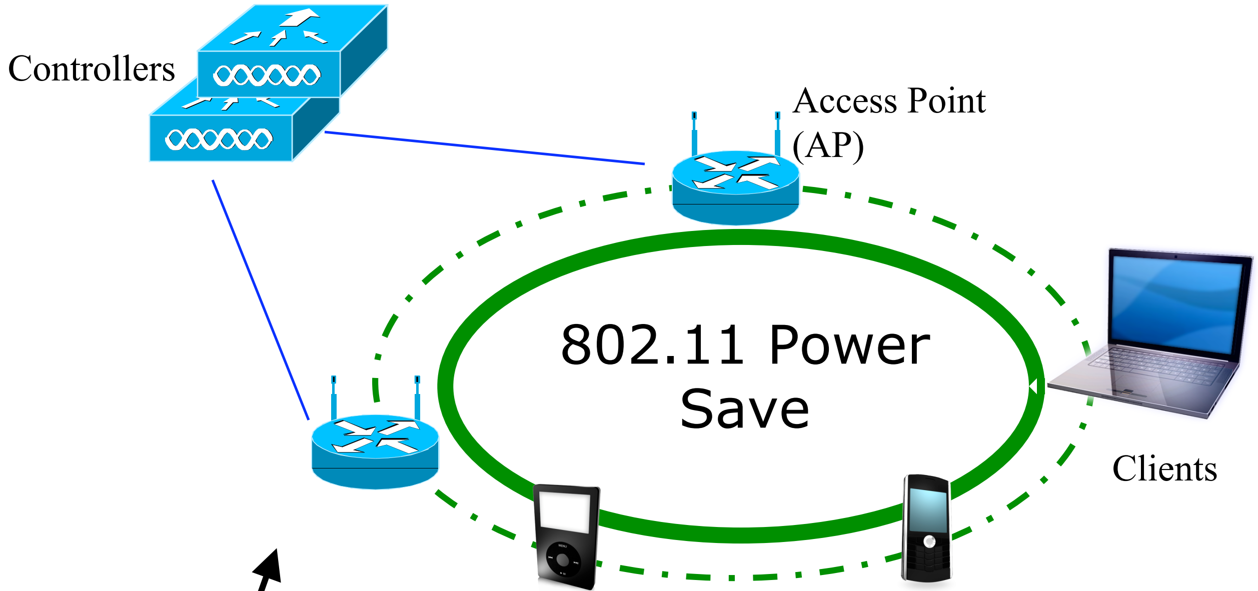
Enterprise Distribution Network – WiFi Access





- WiFi operates in unlicensed band:
  - Highly variable signal strengths
  - Short range, limited coverage, interference
- AP infrastructure is always ON
  - Reliable WLAN, efficient client roams
- Clients'/AP collaborative reliance for PS
  - Clients are ultimate energy beneficiaries

802.11 Power Save Features

- **Power Save (PS-Poll) – 802.11-2007**

  A STA enters PS mode, and while in in PS mode it listens to selected beacons. If beacon indicates packets buffered for that STA, the STA sends a PS-Poll frame to the AP to fetch the packets.

- **Automatic Power Save delivery (APSD) – 802.11-2007**

  The power save mechanism for Quality-of-Service (QoS) enabled STA and APs and allows per-stream (Access Category) power save.

- **Fast BSS Transition – Pub. 802.11r-2008/802.11mb**

  A STA can roams between 2 APs in a power efficient manner. Fast BSS transition allows use of a security key hierarchy and QoS negotiation during the fast transitions process.

Approved

802.11 Power Save Features

- **Proxy ARP – 802.11v, WiFi Alliance (WFA)**

  The AP has the ability to proxy ARP frames for the STA. This is intended to enable the STA to remain in power-save for longer periods of time.

- **TIM Broadcast – 802.11v**

  AP periodically transmits a TIM frame, which is shorter than Beacons and transmitted at a higher rate, to indicate traffic buffered for a STA.

- **WNM Sleep Mode - 802.11v, WFA**

  WNM Sleep Mode is an extended STA power save mode in which a STA need not listen for every DTIM Beacon frame, and AP does not perform GTK/IGTK updates.

In-Development

802.11 Power Save Features

- **BSS Termination Notification – 802.11v, WFA**

  An AP notifies STAs that the AP will be powering-down, e.g. during non-peak hours. This enables STA to sleep longer, wake when the AP wakes, or STA can transition to a wake AP.

- **Traffic Filtering Service – 802.11v, WFA**

  Allows AP to send only traffic that matches STA-specified filters. This can reduce the number of non-essential frames from being sent to the STA, allowing STA to remain in Standby.

- **Flexible Multicast System (FMS) – 802.11v**

  AP sends multicast/broadcast frames at multiples of the DTIM interval, and at higher data rate, allowing longer power save state for STA.

- **IBSS Mode Power Save – 802.11-2007**

  Power Save mode for 2 STAs in IBSS (adhoc) mode, where STAs co-ordinate Sleep duration and interval. Problematic due to vendor-specific heuristics.

802.11 Power Save Observations

- AP Infrastructure enables power-save on Clients devices
  - Regulate infrastructure for lowering Client energy usage
- Legacy (PS-Poll) and QoS (APSD) Power Save
  - Algorithms are vendor-specific implementations
  - Results are dependent upon deployment and configuration
  - VoIP Application can save 15-40% power (WiFi Alliance WMM Power Save) over PS-Poll
- Considerable new energy savings effort (802.11v) underway
  - WiFi Alliance, Field deployment results anticipated ('10/'11)
- IBSS/Peer-Peer Power Save
  - Not widely deployed – current usage is Infrastructure mode
  - Emerging with P2P use cases

WiMAX / IEEE 802.16:
Energy Saving Aspects

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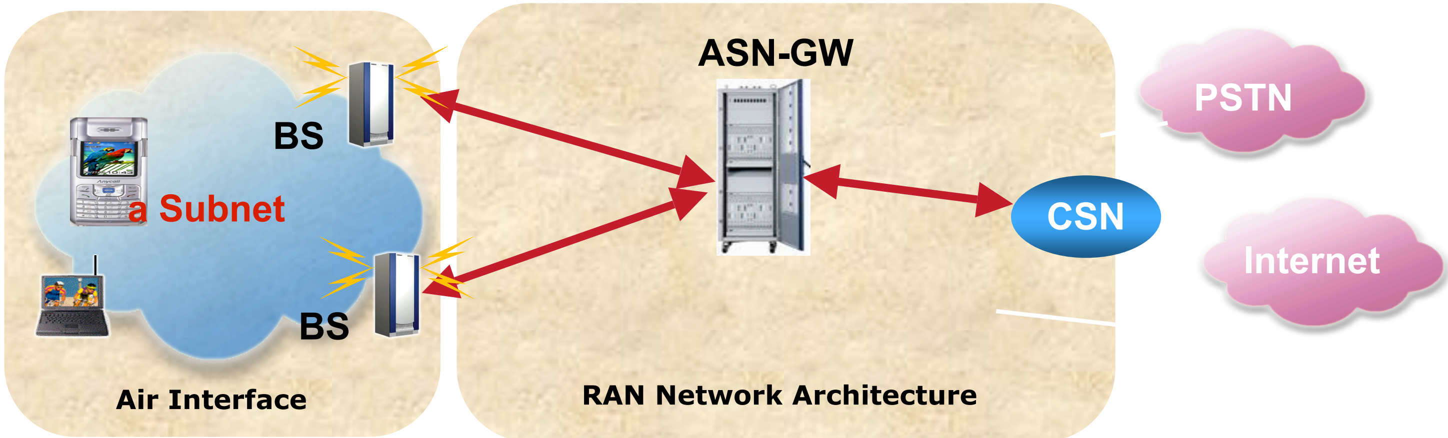
WiMAX in a Snapshot



- Flat IP architecture
- Multiple Carrier frequencies supported, roadmap for global roaming
- Point to multi-point structure
- Channel BW: 5, and 10MHz (roadmap for 15, and 20MHz)
- Scalable OFDMA based DL and UL
- TDD Duplexing mode (Supports FDD in future releases)
- Optimized for Multiple Antenna technology support
- Efficient Power Saving modes (sleep and Idle mode)
- Advanced Security

- Efficient QoS for multimedia
- Optimized hard handoff mobility (with Fast Cell Selection in future release)
- Power Saving modes (sleep and Idle mode)
- Advanced Security
- Adaptive Modulation and Coding
- Link adaptation
- Multicast/broadcast services

Energy Saving Aspects

- Downlink (Forward Link): From base station to mobile stations
  - Coverage enhancement techniques
  - Advancements in developing equipments

- Uplink (Reverse Link): From mobile stations to base station
  - Power Saving modes
  - Coverage enhancement techniques
  - Peak to Average ratio reduction
  - Advancements in developing equipments

Downlink

- Coverage enhancement techniques requires less Transmit powers to reach the signal to the cell edge
  - –Multiple antenna schemes
  - –HARQ
  - –Interference management
  - –Enhanced receive mechanisms in the mobile stations

- Advancements in developing equipments
  - –More efficient Power amplifiers
  - –Higher antenna gains
  - –lower noise figures
  - –Etc.

Uplink

- Power Saving modes for prolonging device battery life and reducing consumed energy
  - Three states: active, sleep, and idle mode
  - Sleep mode
    - happens more frequently
    - faster transition to active mode
    - device is still registered at the BS
    - conserves les power than idle mode
  - Idle mode
    - device is not registered at the BS
    - happens less frequently
    - slower transition to active mode
    - requires paging to return to active mode (or activation from device)
    - conserves very high amount of power

Some Power Save Observations

- Coverage enhancement techniques requires less Transmit powers to reach the signal to the cell edge
  - Multiple antenna schemes (next release for CPEs)
  - HARQ
  - Interference management
  - Enhanced receive mechanisms in the base station
- Peak to Average ratio reduction
  - Reduces power amplifier backoff
  - Increases the power amplifier efficiency
  - Requires less generated power for the same transmit power
- Advancements in developing equipments
  - Using small size dices for chipsets, redusing average power consumption
  - More efficient Power amplifiers
  - Higher antenna gains
  - lower noise figures
  - Etc.

WiMAX Chipset Evolution

WiMAX Wave1	WiMAX Wave2	WiMAX + WiFi	WiMAX+WiFi +GPS, BT etc. Multi-Mode
Process = 180-90nm	Process = 90-65 nm	Process = 65-45 nm	Process = 45 nm
Avg. Pwr = ~1.2W	Avg. Pwr=~800mW	Avg. Pwr=~600mW	Avg. Pwr = ~450mW
Avg. Size ~625mm2	Avg. Size~400mm2	Avg. Size~225mm2	Avg. Size~100mm2
WiMAX only 2 chip solution	Wave2 WiMAX 2 chip solution	WiMAX and WiFi SoC Combo solutions	WiMAX+WiFi SoC with Other RF tech. integration
Dominant Devices • CPE Modem • PC Card	**Dominant Devices** • CPE / PC-card • Laptop • UMPC	**Dominant Devices** • MID • PMP • PND • General CE Devices	**Dominant Devices** • General CE Devices • Handset/Mobile Phone
2007	2008	2009	2010

- Avg. Pwr = Full WiMAX Module power consumption including PA under certain Operation mode
- Avg. Size = Full WiMAX Module size

- Source: Data from Sprint WiMAX Chipset Ecosystem Program

Open Discussion